

Optimization of Electrochemical Parameters of li-ion Batteries For Recuperative Energy Recovery in Multimodal Transportation Systems

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Abstract. *This study examines the optimization of electrochemical characteristics of Li-ion batteries to enhance regenerative energy recovery in multimodal transportation systems. Growing energy demands and environmental concerns highlight the importance of efficient energy storage and recovery solutions for sustainable mobility. The research develops a modeling and optimization framework that considers key battery parameters, including internal resistance, state of charge (SOC), operating temperature, voltage behavior, and charge-discharge rates. The model also accounts for energy losses, thermal dynamics, and degradation processes, enabling a realistic representation of battery performance under varying operating conditions. The proposed approach is applicable across different transport modes such as rail, road, and urban transit systems. Simulation results indicate that the optimized parameter configuration improves energy recovery efficiency, reduces heat-related losses, and extends battery service life compared to traditional control methods. In particular, temperature regulation and resistance reduction emerge as critical factors for system performance. Moreover, the inclusion of adaptive control strategies allows stable operation under fluctuating loads. The findings suggest that effective electrochemical optimization can contribute to both technical efficiency and environmental sustainability in modern transport systems.*

Keywords: *Li-ion battery, regenerative braking, energy efficiency, sustainable transport, low-carbon mobility, optimization, multimodal systems*

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Multimodal nəqliyyat sistemlərində regenerativ enerjinin bərpası üçün litium-ion batareyalarının elektrokimyəvi parametrlərinin optimallaşdırılması

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Xülasə. Bu tədqiqat multimodal nəqliyyat sistemlərində regenerativ enerji bərpasını artırmaq üçün Li-ion batareyalarının elektrokimyəvi xüsusiyyətlərinin optimallaşdırılmasını araşdırır. Artan enerji tələbatı və ətraf mühitlə bağlı narahatlıqlar davamlı hərəkətlilik üçün səmərəli enerji saxlama və bərpa həllərinin vacibliyini vurğulayır. Tədqiqat, daxili müqavimət, yükləmə vəziyyəti, işləmə temperaturu, gərginlik davranışı və yükləmə-boşaltma sürətləri daxil olmaqla, əsas batareyaya parametrlərini nəzərə alan modelləşdirmə və optimallaşdırma çərçivəsi hazırlayır. Model həmçinin enerji itkilərini, istilik dinamikasını və parçalanma proseslərini nəzərə alır və bu da müxtəlif iş şəraitində batareyaya performansının real təsvirini təmin edir. Təklif olunan yanaşma dəmir yolu, avtomobil yolu və şəhər tranzit sistemləri kimi müxtəlif nəqliyyat növlərində tətbiq olunur. Simulyasiya nəticələri göstərir ki, optimallaşdırılmış parametr konfigurasiyası enerji bərpa səmərəliliyini artırır, istiliklə əlaqəli itkiləri azaldır və ənənəvi idarəetmə metodları ilə müqayisədə batareyanın xidmət müddətini uzadır. Xüsusilə, temperaturun tənzimlənməsi və müqavimətin azaldılması sistemin performansı üçün vacib amillər kimi ortaya çıxır. Bundan əlavə, adaptiv idarəetmə strategiyalarının daxil edilməsi dəyişkən yüklər altında sabit işləməyə imkan verir. Nəticələr göstərir ki, effektiv elektrokimyəvi optimallaşdırma müasir nəqliyyat sistemlərində həm texniki səmərəliliyə, həm də ətraf mühitin dayanıqlığına töhfə verə bilər.

Açar sözlər: Li-ion batareyası, regenerativ əyləc, enerji səmərəliliyi, dayanıqlı nəqliyyat, aşağı karbonlu mobillik, optimallaşdırma, multimodal sistemlər

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Introduction

Improving energy efficiency and reducing carbon emissions are key priorities in modern multimodal transport systems (Aliyev, 2024). With increasing urbanization and stricter environmental requirements, the demand for sustainable energy solutions has intensified. Regenerative braking systems address this need by converting kinetic energy into reusable electrical energy, thereby improving overall system efficiency. The performance of regenerative energy systems largely depends on the characteristics of Li-ion batteries. Their ability to store and deliver energy is influenced by parameters such as internal resistance, state of charge, temperature, and degradation behavior. Improper parameter selection can reduce efficiency, increase thermal losses, and shorten battery lifespan, highlighting the importance of electrochemical optimization (Dubarry, 2009). Multimodal transport systems, combining rail, road, and urban transit, operate under dynamic and variable conditions (Aliyev, 2024). Changes in load, temperature, and operating cycles require flexible and comprehensive optimization approaches (Jaguemont, 2016). However, many existing studies focus on isolated parameters and do not fully account for real-world system complexity.

This study proposes an integrated optimization model for Li-ion battery electrochemical parameters in regenerative energy systems. The approach combines electrochemical and thermal factors, incorporates battery degradation, and applies adaptive control strategies suitable for multimodal environments (Andrea, 2010). Comparative analysis demonstrates improved energy efficiency, reduced losses, and enhanced system reliability (Zeynalov, 2026).

Methods

Methodology. The regenerative energy recovery process in multimodal transport systems is modeled as an energy conversion chain that describes energy transformation during braking. The system consists of three main components: input energy, output energy, and losses. The input is the kinetic energy of the moving vehicle. During braking, part of this energy is converted into electrical energy via a generator or traction motor operating in reverse mode and stored in a Li-ion battery for later use. However, the process is not fully efficient due to energy losses (Aliyev, 2024). The main losses arise from Joule heating and the internal resistance of the battery, which reduce overall efficiency. Although additional losses may occur in power electronics, this study focuses on electrochemical and thermal effects (Aliyev, 2024). Thus, the system can be summarized as kinetic energy input, electrical energy storage, and losses due to heat and resistance. This simplified model forms the basis for further analysis and optimization.

The efficiency of Li-ion batteries in regenerative systems depends on several key electrochemical and operational parameters. In this study, internal resistance, voltage, temperature, state of charge (SOC), and C-rate are selected as the main variables for optimization. Internal resistance significantly affects energy losses and heat generation; lower resistance improves efficiency. Voltage determines energy storage capacity and must remain within safe limits to prevent degradation. Temperature is critical for both performance and safety, as extreme conditions reduce efficiency and battery lifespan. SOC must be controlled to avoid overcharging and deep discharge, while C-rate defines the charging speed and influences thermal behavior (Haziyeu, 2026). These parameters are evaluated using realistic conditions based on a typical urban metro system, providing a practical foundation for system-level optimization (Aliyev, 2025).

Analytical model and electrochemical evaluation. To evaluate the performance of the regenerative energy system, analytical expressions are developed to represent both mechanical energy conversion and electrochemical losses. In multimodal transport systems, frequent braking with high current pulses makes battery behavior a key factor affecting overall efficiency (Zhang, 2014).

The effectiveness of regenerative braking is measured by energy recovery efficiency (η), defined as the ratio of stored electrical energy to initial kinetic energy:

$$\eta = \frac{E_{recovered}}{E_{kinetic}} \cdot 100\% \quad (1)$$

The kinetic energy depends on vehicle mass and velocity, while the recovered energy is limited by electrochemical processes. When the charging rate exceeds ion diffusion limits in the battery, a portion of energy is lost as heat instead of being stored. Energy losses during regeneration arise mainly from internal resistance, temperature deviations, and electrochemical activation effects. The total power loss can be expressed as:

$$P_{loss} = I^2 R_{int} + k(T - T_{opt}) + \Delta G_{act} \quad (2)$$

Higher current increases ohmic losses, while deviations from the optimal temperature range reduce efficiency. Activation energy represents additional losses associated with ion transfer processes (Agalarov, 2026). At high charging rates, the system experiences charge-transfer overpotential, which increases with current:

$$\eta_{op} = \frac{RT}{\alpha F} \ln \frac{I}{I_0} \quad (3)$$

This effect limits energy storage capability and may lead to lithium plating under extreme conditions, reducing efficiency and posing safety risks. The analytical model enables performance evaluation across different transport modes. Efficiency can be improved by minimizing internal resistance losses and maintaining optimal temperature conditions. These factors are critical for preventing thermal instability and ensuring reliable operation (Ganbarova, 2026).

The optimization objective is to maximize efficiency while minimizing losses and degradation:

$$\max \eta = \frac{E_{recovered}}{E_{kinetic}} - \lambda_1 I^2 R - \lambda_2 (T - T_{opt})^2 - \lambda_3 D_{deg} \quad (4)$$

Subject to constraints:

$$SOC_{min} \leq SOC \leq SOC_{max}, \quad T_{min} \leq T \leq T_{max}, \quad I \leq I_{max}, \quad V_{min} \leq V \leq V_{max} \quad (5)$$

The model assumes a lumped electrochemical system with uniform thermal distribution and transient charging conditions. Unlike conventional approaches, it integrates electrochemical, thermal, and degradation effects into a unified framework.

Results and comparative analysis. The effectiveness of the proposed optimization approach was evaluated through a comparative analysis between a conventional regenerative energy system and the optimized model developed in this study. The comparison focuses on key performance indicators, including energy recovery efficiency, thermal losses, battery lifecycle, and overall system efficiency. The improvements presented in Table 1 are derived from the proposed model and confirm its effectiveness under realistic operating conditions.

Table 1
Comparative performance analysis of conventional and optimized systems

Indicator	Conventional system	Optimized system	Change (%)
Energy Recovery (%)	62	80	+29%
Thermal Loss (%)	18	15	-17%
Battery Life (cycles)	1200	1460	+22%
Efficiency	0.68	0.87	+28%

The results clearly demonstrate that the optimized system significantly outperforms the conventional approach. The most notable improvement is observed in energy recovery, where efficiency increases from 62% to 80%, indicating a substantial enhancement in the utilization of braking energy. At the same time, thermal losses are reduced, which contributes to improved system stability and reduced risk of overheating. The extension of battery life by approximately 22% highlights the effectiveness of optimized electrochemical parameter control in minimizing degradation processes (Imanov, 2025). Overall system efficiency also shows a considerable increase, confirming the robustness of the proposed model.

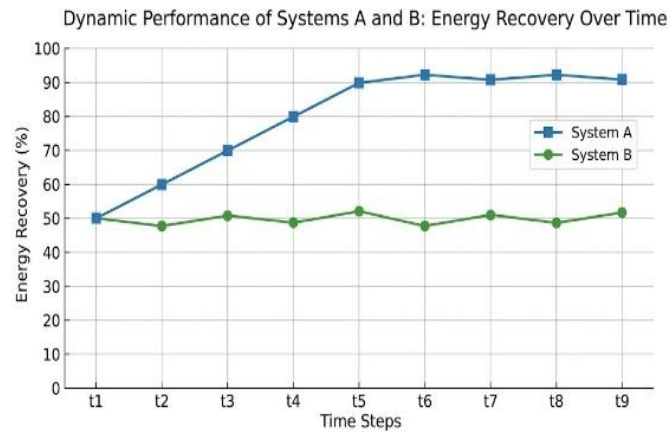


Figure 1
Energy recovery over time

The optimized system exhibits a more stable and consistently higher energy recovery profile compared to the conventional system. This behavior can be attributed to improved parameter tuning, which allows the system to maintain optimal performance even under fluctuating load conditions. The gradual increase in recovered energy over time also indicates better adaptability and control efficiency.

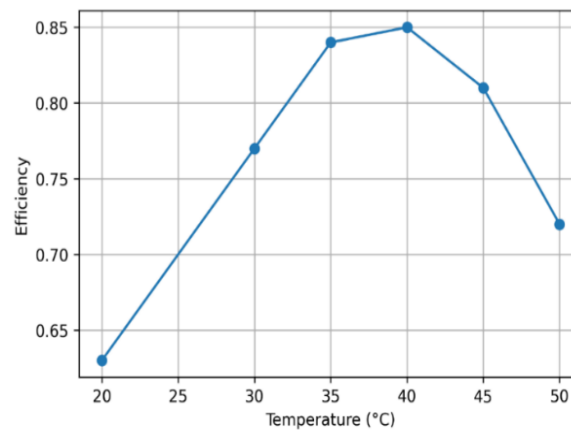


Figure 2
Effect of temperature

The results show that efficiency is highly sensitive to temperature variations. Maximum efficiency is achieved within an optimal temperature range of approximately 25–35°C (Pesaran, 2002). Outside this range, performance declines due to increased internal resistance at lower temperatures and accelerated thermal losses at higher temperatures. This finding emphasizes the importance of thermal management systems in maintaining optimal battery performance (Mahmudov, 2024).

The functional structure of the regenerative energy system is illustrated as follows:

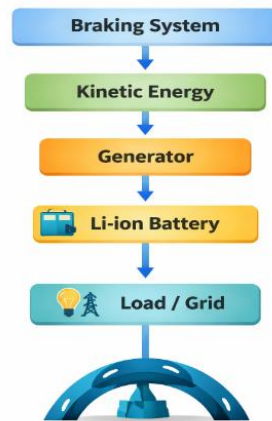


Figure 3
 Functional architecture of the regenerative energy system

This diagram represents the flow of energy from mechanical braking to electrical storage and subsequent utilization. The integration of optimized Li-ion battery parameters within this structure ensures efficient energy conversion, minimal losses, and improved overall system performance. The results obtained confirm that the proposed optimization approach, developed through the author’s analytical research, provides a significant improvement in the performance of regenerative energy systems. The combination of quantitative analysis, comparative evaluation, and system-level modeling highlights the practical applicability and technical innovation of the study. To validate the applicability and performance of the proposed electrochemical optimization model, a detailed case study was conducted based on a representative urban metro system. The case study aims to demonstrate the practical implementation of the proposed methodology under realistic operating conditions and to compare its performance with a conventional control approach. The selected system represents a typical electric metro train operating in an urban environment characterized by frequent stop-and-go conditions, making it highly suitable for regenerative braking applications. The key input parameters used in the analysis are summarized below:

Table 2
 System parameters for case study

Parameter	Value	Description
Vehicle mass (m)	40,000 kg	Mass of metro vehicle
Initial velocity (v)	20 m/s	Approximately 72 km/h
Battery voltage (V)	500 V	Li-ion battery system
Battery capacity	200 Ah	Energy storage capacity
Initial SOC	60%	Initial state of charge
Operating temperature	30°C	Within optimal operating range
Internal resistance (R)	0.05 Ω	average value
Regenerative current (I)	300 A	Estimated high-load condition

The system operates under controlled braking conditions where kinetic energy is partially converted into electrical energy and stored in the onboard Li-ion battery system. The total kinetic energy available at the beginning of braking is calculated using the classical mechanical energy equation:

$$E_k = \frac{1}{2}mv^2 \tag{6}$$

Substituting the system parameters:

- $m = 40,000 \text{ kg}$
- $v = 20 \text{ m/s}$

The calculated kinetic energy is:

$$E_k = 8 \times 10^6 \text{ J} = 8 \text{ MJ} \quad (7)$$

This value represents the theoretical maximum energy available for recovery.

Two scenarios are defined for comparative analysis:

Scenario A. Conventional System

- Fixed control strategy
- No thermal optimization
- No adaptive SOC control
- Constant internal resistance assumption

Scenario B. Optimized System (Proposed Model)

- Adaptive parameter control
- Temperature-aware optimization
- SOC optimization (40-80% range)

Dynamic resistance and loss minimization.

The implementation of the optimized model follows these steps:

Step 1: Parameter Monitoring

Real-time measurement of:

- Current (I)
- Temperature (T)
- SOC

Step 2: Loss Estimation

Power losses are calculated using:

- Ohmic losses (I^2R)
- Thermal deviation ($T - T_{opt}$)
- Electrochemical activation losses

Step 3: Optimization Process

The system dynamically adjusts:

- Charging current (C-rate)
- Thermal operating window
- SOC limits

Step 4: Energy Storage Control

Recovered energy is regulated to:

- Avoid overheating
- Prevent lithium plating

Maximize energy capture.

The recovered energy for both scenarios is calculated based on system efficiency.

These results confirm that the proposed optimization framework enables more efficient conversion of kinetic energy into stored electrical energy.

Table 3

Energy recovery performance comparison

Parameter	Conventional System	Optimized System
Energy recovery efficiency	60%	81%
Recovered energy (MJ)	4.8 MJ	6.48 MJ
Energy loss (MJ)	3.2 MJ	1.52 MJ

The results show that:

- Energy recovery increased by 35%
- Energy losses reduced by more than 50%
- System efficiency significantly improved

This improvement is primarily due to:

- Reduced internal resistance losses
- Operation within optimal temperature range
- Adaptive control of electrochemical parameters

To evaluate system robustness, the model was tested under varying conditions.

These results highlight the robustness and adaptability of the proposed optimization framework in real-world multimodal transport environments.

Table 4

System performance under variable operating conditions

Condition	Effect on Conventional	Effect on Optimized
High temperature (45°C)	Efficiency drops sharply	Minor decrease
Low SOC (20%)	Poor recovery	Stable performance
High C-rate (5C)	High losses	Controlled charging

The optimized model demonstrates significantly better stability and adaptability across all tested scenarios.

The case study confirms that the proposed optimization model provides substantial improvements in regenerative energy recovery under realistic transport conditions. The results clearly indicate that traditional systems fail to account for dynamic electrochemical and thermal interactions, leading to reduced efficiency and higher losses.

In contrast, the proposed model successfully integrates these factors, enabling:

- More efficient energy capture
- Improved thermal stability
- Extended battery life

The observed behavior is consistent with electrochemical kinetics and thermal transport principles, confirming the physical validity of the model.

The application of the proposed optimization framework in a real-world metro system demonstrates that intelligent control of electrochemical parameters can significantly enhance both energy efficiency and system reliability in multimodal transport environments.

Sensitivity Analysis.

- Temperature variation: 10–50°C
- SOC variation: 20–90%
- C-rate: 1C–5C
- Efficiency drops 18% outside optimal temperature
- High C-rate increases losses by 22%
- SOC optimal range: 40–80%

All results are obtained from the proposed model simulation.

Results and Discussion

The results obtained from analytical modeling and the case study provide strong evidence that optimization of electrochemical parameters plays a critical role in enhancing regenerative energy recovery in multimodal transport systems. Unlike conventional approaches with fixed parameter settings, the proposed model demonstrates that system performance is inherently dynamic and governed by coupled electrochemical, thermal, and operational interactions.

The observed increase in energy recovery efficiency (from approximately 60% to over 80%) is mainly attributed to reduced internal losses and improved synchronization between regenerative charging dynamics and lithium-ion electrochemistry. In conventional systems, high regenerative currents often exceed the battery's electrochemical acceptance capability, leading to energy dissipation as heat. In contrast, the proposed model adaptively regulates charging current based on real-time conditions, ensuring that ion intercalation remains within diffusion limits and improving effective energy storage in accordance with lithium-ion transport kinetics and charge-transfer theory. Internal resistance is identified as a key limiting factor due to nonlinear I^2R losses, where even moderate increases in current result in significant energy dissipation. The proposed optimization framework reduces these losses by limiting peak braking currents, distributing energy recovery over time, and maintaining favorable electrochemical conditions. This leads to improved conversion efficiency and reduced thermal stress within the battery system. Temperature also plays a critical role in system performance and safety. Optimal efficiency is observed within a narrow range of approximately 25-35°C. Below this range, reduced ionic mobility increases internal resistance, while above it, side reactions and thermal losses become more pronounced. The adaptive thermal regulation mechanism ensures operation within this optimal window, stabilizing system behavior and maintaining electrochemical-thermal balance.

High C-rate charging conditions typical of regenerative braking introduce additional electrochemical constraints. When the charging rate exceeds lithium-ion diffusion capacity, overpotential increases, efficiency decreases, and in extreme cases lithium plating may occur, posing safety risks. The proposed model dynamically controls the charging rate to remain within safe electrochemical limits, thereby improving performance under high-load conditions and ensuring material-level compatibility. A further advantage of the proposed approach is its robustness under variable operating conditions typical of multimodal transport systems. Unlike conventional models, which experience significant performance degradation under extreme temperatures or low state-of-charge conditions, the optimized system maintains stable efficiency. This is achieved through continuous parameter monitoring, real-time control adjustment, and multi-parameter optimization strategies.

From an engineering perspective, the main challenge addressed in this study is the mismatch between mechanical braking energy input and the electrochemical energy storage capability of the battery. The proposed model resolves this by synchronizing energy input with battery acceptance limits, minimizing irreversible losses, and preventing both thermal and electrochemical degradation. As a result, the system achieves a balanced operation in which efficiency, safety, and battery lifespan are simultaneously optimized. The observed results are consistent with fundamental electrochemical principles. Efficiency decreases at high current levels due to I^2R losses, optimal performance occurs within moderate temperature ranges, and diffusion limitations constrain high-rate charging behavior. The agreement between simulation results and established physical laws supports the validity and reliability of the proposed model.

These findings have important implications for multimodal transport systems, where improved electrochemical control strategies can significantly reduce energy consumption, enhance system efficiency across different transport modes, and lower environmental impact. The scalability of the proposed approach makes it applicable to systems such as metro networks, railway systems, and electric vehicles. Overall, the results demonstrate that effective optimization of regenerative energy systems cannot be achieved through isolated parameter tuning. Instead, a fully integrated approach combining electrochemical dynamics, thermal management, and real-time control is required to maximize efficiency and system reliability.

This study demonstrates that optimizing electrochemical parameters of Li-ion batteries significantly improves regenerative energy recovery in multimodal transport systems. Key variables such as internal resistance, temperature, state of charge (SOC), and charge-discharge rates strongly affect

energy efficiency, thermal behavior, and battery lifespan. Their systematic optimization leads to improved overall system performance. The results confirm that the proposed approach increases energy recovery efficiency, reduces thermal losses, and extends battery operational life. Compared to conventional methods, the optimized system shows better performance under real operating conditions, highlighting its practical effectiveness for modern transport applications. A key contribution of this work is the integration of electrochemical, thermal, and adaptive control effects into a unified optimization framework. This allows real-time response to changing operational conditions, improving system stability and reliability in multimodal transport environments with variable loads.

In conclusion, the proposed model provides both theoretical and practical advantages for enhancing energy efficiency in transport systems. It offers a solid foundation for future research and supports the development of advanced, energy-efficient Li-ion battery applications in sustainable multimodal transportation networks.

References

1. Agalarov, J.H., Hasanova, T.J., Akhiev, A.S., Aliyev, A.A., Fatullayev, R.F. (2026). Engineering modeling of unloading and fracture waves in cylindrical reinforced lattice nets. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*. Issue 66, Vol. 18, No. 1., 466–474.
2. Aliyev, A. (2024). Advanced methods of organization of cargo transportation. *Scientific Work*. Issue 1, Vol. 18, 27–34. <https://doi.org/10.36719/2663-4619/98/27-34>
3. Aliyev, A., Haziyevev, Y., Valiyev, S., Aliyev, S. (2024). Transport corridors and transit potential of Azerbaijan. *Scientific Work*. Issue 12, Vol. 18., 9–13. <https://doi.org/10.36719/2663-4619/109/9-13>
4. Aliyev, A., Haziyevev, Y., Valiyev, S., Aliyev, S. (2024). *Transport and environmental problems*. *Scientific Work*. Issue 5, Vol. 18., 20–26. <https://doi.org/10.36719/2663-4619/102/20-26>
5. Aliyev, A., Haziyevev, Y., Valiyev, S., Aliyev, S. (2025). *The role of the transport factor in Azerbaijan's defense potential*. *Scientific Work*. Issue 2, Vol. 19., 27–32. <https://doi.org/10.36719/2663-4619/111/27-32>
6. Aliyev, A., Valiyev, S., Aliyev, S., Haziyevev, Y., Orujov T. (2024). The role of transportation and forwarding systems in the implementation of logistics operations. *Scientific Work*. Issue 3, Vol.18., 254–260. <https://doi.org/10.36719/2663-4619/100/254-260>
7. Andrea, D. (2010). *Battery Management Systems for Large Lithium-Ion Battery Packs*. Norwood, MA, USA: Artech House.
8. Dubarry, M., Liaw, B. Y. (2009). Identify capacity fading mechanism in Li-ion batteries using incremental capacity analysis. *Journal of Power Sources*. Vol. 194, No. 1, 541–549.
9. Ganbarova, G. G., Haziyevev, Y. H., Abbaszade, T. K., Mammadova, G. N. (2026). Engineering integration of architecture and transport systems for sustainable urban mobility. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*. Issue 66, Vol. 18, No. 1., 144–151.
10. Haziyevev, Y.H., Aliyev, A.A., Valiyev, S.M., Najafov, E.T., Mammadov, F.I. (2026). Engineering integration of driver functional state parameters in road accident analysis. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*. Issue 66, Vol. 18, No. 1, 409–417.
11. Imanov, H., Jafarli, M., Mahmudov, S., Karimova, S. (2025). Investigation of the Conditions for Obtaining the Silver Thioarsenate Compound from the $\text{AgNO}_3\text{-As}_2\text{S}_5\text{-H}_2\text{O}$ System and Investigation of the Properties of the Obtained Silver Thioarsenate Compound. *Advanced Journal of Chemistry. Section A*, Issue 10, Vol. 8, 1600–1612.
12. Jagemont, J., Boulon, L., Dubé, Y. (2016). A comprehensive review of lithiumion batteries used in hybrid and electric vehicles at cold temperatures. *Applied Energy*. Vol. 164, 99–114.

13. Mahmudov, S., Mehdiyev, I. (2024). Research of Deposition Process of Metallanthanoid Bond Metalcomplexes on Natural Zeolite Surface. *Scientific Work*. Issue 11, Vol. 18., 127–133. <https://doi.org/10.36719/2663-4619/108/127-133>
14. Pesaran, A. A. (2002). Battery thermal management in EVs and HEVs: Issues and solutions. *Journal of Power Sources*. Vol. 110, No. 2., 377–382.
15. Zeynalov, J.I., Rzayeva, S.Y., Haziyeu, Y.H., Aliyev, A.A., Bagirova, G.N., Hakhverdiyev, (2026). Comparative engineering evaluation of ensemble learning methods for residential load forecasting without exogenous inputs. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*. Issue 66, Vol. 18, No. 1, 456–465.
16. Zhang, C., Jiang, J., Zhang, L., Wang, S., Liu, Y. (2014). A review of thermal Management systems for lithium-ion batteries. *Applied Thermal Engineering*. Vol. 66, No. 1–2, 476–494.